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JADS End-to-End Test- Distributed Simulation Using Satellites

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JADS END-TO-END TEST
DISTRIBUTED SIMULATION USING SATELLITES

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ABSTRACT: *The End-To-End (ETE) Test, conducted under the auspices of the Department of Defense Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E), developed a synthetic test environment using simulations connected by satellite that can be used for future testing, training and doctrinal development. This synthetic environment was used initially to assess the feasibility of using distributed simulation to conduct developmental and operational testing of the Joint Surveillance Target Attack Radar System (Joint STARS). As designed and built, it may be used to conduct future testing of systems such as the Block II Joint STARS, the common ground station (CGS), the All Source Analysis System, and the Block II Army Tactical Missile System (ATACMS).*

This paper will describe the synthetic test environment, the design considerations involved in developing the synthetic environment, the modifications of the distributed interactive simulation (DIS) standards required to accommodate the environment, and the difficulties involved in verifying and validating the environment. Additionally, some of the pluses and minuses of making this environment high level architecture-compliant in the future will be discussed.

1. End-To-End Test Overview

The End-To-End (ETE) Test was one of the three tests conducted under the auspices of the Department of Defense Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E). JADS was chartered to investigate the utility of advanced distributed simulation (ADS) technologies for the support of developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The program is Air Force led with Army and Navy participation. Science Applications International Corporation (SAIC) provided contracted technical support to the ETE Test.

The ETE Test was designed to evaluate the utility of ADS to support the testing of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems. It conducted its test and evaluation utility evaluation in an ADS-enhanced test environment using the Joint Surveillance Target Attack Radar System (Joint STARS) as the system under test immersed in a representative C4ISR environment. The ETE Test also evaluated the capability of the JADS Test Control and Analysis Center to control a distributed test of this type and to remotely monitor and analyze test results.

The ETE Test used distributed interactive simulation (DIS) to assemble a synthetic environment (SE) for testing C4ISR systems. The intent was to provide a complete, robust set of interfaces from sensor to weapon system, including the additional intermediate nodes that would be found in a tactical engagement. The test traced a thread of the complete battlefield process from target detection to target assignment and engagement at corps level using ADS. It allowed the tester to evaluate the entire thread, or the individual contribution of any of the parts, and to evaluate what effects an operationally realistic environment had on the system under test.

The test concept was to use ADS to supplement the operational environment experienced by the E-8C and light ground station module (LGSM) operators by adding additional entities to the battlefield seen by Joint STARS.

Also, by adding additional elements of the command, control, communications, computers and intelligence (C4I) systems that Joint STARS interacts with and a weapon system to engage targets, the test team could evaluate a thread of the complete battlefield environment from target detection to target assignment and engagement.

This was accomplished by adding approximately ten thousand simulated targets to the live targets seen by the radar on board the E-8C aircraft. As a result, a battle array approximating the major systems present in the area of interest was presented to the operators both in the air and on the ground. A network was then constructed with nodes representing appropriate C4I and weapon systems that provided a more robust cross section of players for interaction with the E-8C and LGSM radar surveillance operators.

Several components were required to create the ADS-enhanced operational environment used in the ETE Test. In addition to Joint STARS, the ETE Test required a simulation capable of generating thousands of entities representing the rear elements of a threat force. For this purpose, the ETE Test team selected the U.S. Army's Janus simulation.

Also, a simulation of the Joint STARS radar, called Virtual Surveillance Target Attack Radar System (VSTARS), that simulated both moving target indicator (MTI) radar and synthetic aperture radar (SAR), was developed to insert the simulated targets into the radar stream on board the E-8C while it was flying a live mission.

The target data were sent to the aircraft for processing by VSTARS using satellite transmission. More will be said about this later.

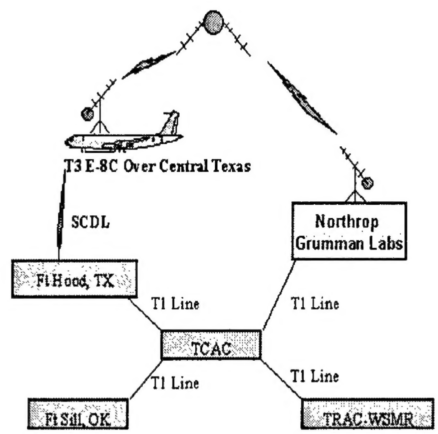
Other capabilities used to support the test included simulations or subsets of the Army's artillery command and control process and a simulation of the Army Tactical Missile System (ATACMS).

The ETE Test consisted of four phases. Phase 1 developed or modified the components that allowed the mix of live and simulated targets at an E-8C operator's console and LGSM operator's console. Phase 2 evaluated the utility of ADS to support DT&E and early OT&E of a C4ISR system in a laboratory environment. Phase 3 moved components of VSTARS onto the E-8C aircraft, ensured that the components functioned properly, and checked that the synthetic environment properly interacted with the aircraft and the actual LGSM. Phase 4 evaluated the ability to perform test and evaluation in a synthetically enhanced operational environment using typical operators.

More detailed information on the ETE Test can be found in the ETE Test reports available at http://www.JADS.abq.com. (After 1 March 2000 refer requests to HQ AFOTEC/HO, 8500 Gibson Blvd SE, Kirtland Air Force Base, New Mexico 87117-5558, or SAIC Technical Library, 2001 North Beauregard St. Suite 80, Alexandria, Virginia 22311.)

2. ETE Test Synthetic Environment

The Phase 4 ETE Operational Test synthetic environment, as previously described, is shown in Figure 2-1.



SCDL = surveillance control data link
T1 = digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
TRAC = U.S. Army Training and Doctrine Command Analysis Center
WSMR = White Sands Missile Range, New Mexico

Figure 2-1. ETE Test Synthetic Environment

As can be seen, the synthetic environment was composed of two networks, a standard wide area network (WAN) for passing DIS protocol data units, voice, and Advanced Field Artillery Tactical Data System traffic, and a satellite link for passing simulation data and messages to the aircraft.

Nothing more will be said about the standard WAN except that it was very reliable and lightly loaded for reasons to be discussed later. More details can be found in the ETE Test Phase 4 report referenced earlier.

The satellite link was established in order to provide information about the simulated targets to VSTARS on board the test aircraft (T3). It served the function of a virtual radar antenna. Once the target data were received, they were made available to VSTARS upon demand, mixed with live returns as appropriate and presented to the radar surveillance officers on board the aircraft. The aircraft's surveillance control data link (SCDL) enabled it to also transmit the radar reports to ground stations located on Fort Hood, Texas.

Using this technique, an operational scenario consisting of ten thousand targets located in western Iraq was overlaid with a real exercise taking place at Fort Hood. Fort Hood could target any of the targets in the scenario based upon the radar reports, engage them with a virtual ATACMS fired from Fort Sill, Oklahoma, and destroy the targets that were being generated at the U.S. Army Training and Doctrine Command Analysis Center, White Sands Missile Range, New Mexico (TRAC-WSMR). Once the targets were destroyed by the ATACMS, the TRAC-WSMR operator could scatter or relocate the survivors.

As an example, one of the engagements during the test was against an Iraqi corps headquarters that was identified using virtual radar reports and other forms of intelligence. It was struck with several ATACMS that caused it to relocate to an alternate site. The personnel at Fort Hood tracked the movement of the survivors using the virtual MTI radar. They waited until everyone had arrived, verified the new position with a virtual SAR, and than hit the corps headquarters with another salvo of ATACMS.

3. Synthetic Environment Restraints and Design Considerations

The conceptual model for the ETE Test synthetic environment was conceived almost five years ago and made use of the then prevalent methodology for distributed simulation, distributed interactive simulation. Many of the early restraints faced by the ETE Test designers would have been alleviated had the high level architecture (HLA) been available. This will be discussed in more detail at the end of this paper.

The foremost design constraint for the ETE Test synthetic environment was the requirement to eventually (Phase 4) broadcast all the required target data to the aircraft while it was in flight over the target area. This requirement, coupled with the prohibition against changing any hardware in the aircraft, was a major factor in the evolving design of the ETE Test synthetic environment.

The requirement called for providing data on more than five thousand targets to VSTARS on board the aircraft. By using the DIS entity state protocol data unit (ESPDU) to convey this information, at a minimum 1152 bits per ESPDU, it would require nearly 6 million bits of data to provide a single update to the aircraft

The DIS standard also called for an update of each entity's state to be issued if a predetermined time had elapsed since any entity's last ESPDU. These ESPDUs are normally referred to as the heartbeat. This was done for several reasons, none of which apply to the ETE Test. The default length of time between heartbeats is five seconds. In addition, DIS uses a process called dead reckoning to "... limit the rate at which simulations must issue updates for an entity." [1] On a regular basis, the simulation compares the internal model of an entity to a simpler model based on a specified dead reckoning algorithm. When the two models deviate by a predetermined amount, the simpler model is updated and an ESPDU is broadcast so that other simulations on the network can update their model of the entity.

What this meant in terms of the environment was that we needed a minimum effective bandwidth between the ground and the plane if we were to transmit ESPDUs of around 1.2 megabits per second.

This bandwidth requirement certainly exceeded any capability currently installed on the aircraft, or even planned, and would have to be reduced if the test had a chance of succeeding.

It also would require a major portion of the T1 communications lines planned for the conventional WAN, and if broadcast to all nodes, as specified in the DIS standard, could cause problems.

Other issues with the DIS standard, such as the coordinate system used in DIS and the multiple conversions required, were present, but minor in comparison to the bandwidth problem.

4. The ETE Test Solution

It was obvious from the beginning that there was neither a need, nor a method, to transmit this amount of data from the ground to the aircraft. The ESPDU was designed to satisfy everybody, which is why it can contain at least 1152 bits of data.

VSTARS had not yet been developed at this stage of the synthetic environment design. Therefore, it was a simple matter to include in its design a data packet that would contain the data required for VSTARS. This data packet, later identified as the VSTARS data packet (VDP), was formed from the ESPDU using a subsystem of VSTARS called the ground network interface unit (GNIU).

The function of the GNIU was to receive the ESPDUs from the WAN and process them into VDPs. This involved converting the positional data from world coordinate system to the topocentric coordinate system used by the radar and a reduction of both positional data and velocity data to 16-bit accuracy. Also included was the conversion of the entity orientation data to a 16-bit orientation in the two-dimensional viewing plane.

The end result was a 192-bit packet (Table 4-1) that provided all the data needed to insert targets from the operational scenario into the radar images provided by VSTARS. This one step reduced the bandwidth requirement down to 200 kilobits (Kbits) per second.

Table 4-1. VSTARS Data Packet (VDP)

VSTARS Data Packet		Field Size (bits)
Time Stamp		32
Entity ID		16
Entity Type	Category	8
	Subcategory	8
	Specific	8
	Extra	8
Entity Linear Velocity	X-Comp.	16
	Y-Comp.	16
	Z-Comp	16
Entity Location	X-Comp.	16
	Y-Comp.	16
	Z-Comp	16
Entity Orientation	X-Comp.	8
	Y-Comp.	8
VDP Size		192 bits

Noticeably missing from the VDP is the dead reckoning parameter field (320 bits) from the ESPDU. Dead reckoning is performed by the air network interface (ANIU) subsystem of VSTARS. The ANIU receives the VDP from the GNIU and performs dead reckoning on those entities with a velocity other than zero. It then stores the data on each entity, moving and nonmoving, in VSTARS' target database. It was determined during the design phase of VSTARS that simple first-order dead reckoning was adequate, and it was written into the code for the ANIU.

The final design step taken to reduce the bandwidth requirements was to make the heartbeat period adjustable within Janus. Bandwidth requirements were not the only consideration in doing this, as the broadcasting of a thousand ESPDUs a second was no small task. Simply extending the heartbeat period to two minutes would reduce the bandwidth requirements for the air-to-ground link to less than 9 Kbits per second. This act was made possible because the ETE Test synthetic environment was a closed environment specific to a test, and no one would be allowed to enter the environment without prior coordination.

The overloading of portions of the network, due to the broadcast of so many ESPDUs, was avoided by designing the network so that only VSTARS received them.

5. Tuning the Environment

Phase 2 of the test was conducted in a laboratory environment and was in effect a rehearsal of Phase 4, where we would be required to link the GNIU and ANIU with satellite communications.

Phase 2 allowed the ETE Test team to characterize the ESPDU flow over the lifetime of the test event. Five scenarios, each lasting six hours, were used in Phase 2 and would be used during the Phase 4 operational test. Though different, each exhibited certain characteristics that proved we would have a problem during Phase 4.

The first problem encountered was the fact that we had gotten carried away in our zeal to add entities to the battlefield and now had Janus populating the battlefield with ten thousand entities. The second problem was the fact that battlefield actions, and accurate simulations of battlefield actions, are incoherent. In all of the scenarios there were periods of intense activity that created bursts of hundreds of ESPDUs per second. There were also periods where it was necessary to check to see if the scenario was still running.

Our first approach to solving this problem was to throw the DIS standards on heartbeat out the window. VSTARS stores the location of each entity within its area of interest in a target database. The location of each target will remain the same until new data are received from the ANIU. Targets that are moving are updated by the dead reckoning function of the ANIU. Targets that are stationary do not need updating. There is no need for a heartbeat except to initially inform the target database of the location of the nonmovers. If an entity starts moving, an ESPDU will be broadcast and dead reckoning will occur. If an entity stops, an ESPDU will be broadcast with zero velocity values and no further updates are needed.

This was implemented by modifying the scenarios to include an initial period of no activity whatsoever. During this period the heartbeat is turned on, at a rate within the satellite link's capability, and the starting position of each target is stored in the target database. Once the target database has the starting data on all the entities, the heartbeat is turned off, the scenario movement is started, and the only ESPDUs broadcast are those that indicate a change in speed or direction.

This effectively reduced the number of ESPDUs broadcast in any given period of time, as most of the ESPDUs previously broadcast were the result of the heartbeat.

Further tuning of the scenarios also helped reduce the peak protocol data unit rates by spreading out, over a period of time, the start of convoys and other battlefield actions that generate ESPDUs.

The final stage in tuning the environment was to look at the satellite transmission itself. Extensive testing showed that we could reliably transmit and receive up to thirty-four VDPs per second. Above this rate, dropouts occurred and data were lost. Unfortunately, there still existed within the scenario periods when the ESPDU rate exceeded the maximum rate that could be reliably transmitted via the satellite link.

The solution arrived at by the ETE Test team was to restrain the rate of transmission of the VDPs, to ensure reliable transmission, and to buffer the excess data. In this way, periods of high activity would be spread over several seconds. This is shown in Table 5-1.

Table 5-1. VDP Transmission Rate

Seconds	1	2	3	4	5	6	7	8	9
ESPDU/VDP Generated by Scenario	68	14	8	19	26	42	39	16	12
VDP Buffered Awaiting Transmission	38	22	0	0	0	12	21	7	0
VDP Transmitted Via Satellite	30	30	30	19	26	30	30	30	19

Obviously, this adds latency to the transmission of the data resulting in vehicles turning or changing speed several seconds late. Two factors alleviated this problem.

The first was the scope of the exercise. Referring to Table 5-1, in the first three seconds data for thirty entities are delayed one second and data for eight entities are delayed for two seconds; this was out of 10,000 entities with several thousand moving.

The second factor was the radar itself. The Joint STARS radar is not perfect. Locational error exists in every detection of a target. A target moving at a ground speed of 40 kilometers/hour will only travel approximately 22 meters during the two-second delay described above. The radar also revisits a target at a rate that is measured in seconds. Therefore, even with the delay, the target may well be updated with new data before the radar revisits it.

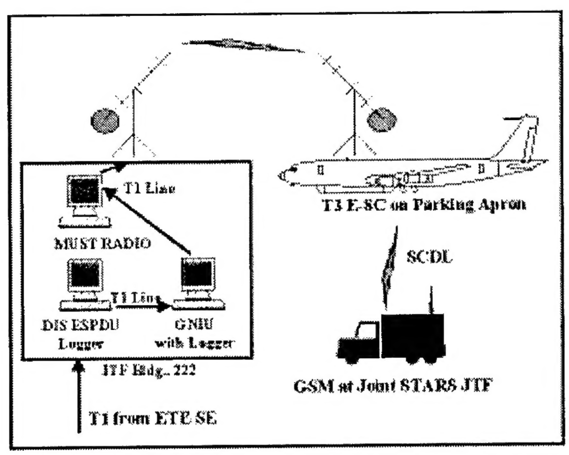
Both of these factors resulted in no observable differences because of latency in the radar images that were presented to the radar surveillance officers.

6. Verification and Validation Issues

The ETE Test synthetic environment underwent extensive testing and verification and validation (V&V) prior to the live flights. Details are available on the JADS' web site, in addition to previously published reports and papers presented at various conferences to include this one. It is not the intent of this paper to discuss the details of the V&V, but rather to discuss a phenomenon associated with using satellite transmission to transmit simulation data to a Joint STARS aircraft.

The phenomenon is simply that you cannot thoroughly test, nor V&V, the system until you pay the big bucks and use it during the test. The T3 aircraft used in the ETE Test is such a costly and scarce resource that every flight counts. There would not be a flight dedicated only to V&V, even if we had been willing to pay for it.

The testing and V&V configuration, shown in Figure 6-1, was as close to flight conditions as it was possible to duplicate. System integration tests and V&V were conducted using line-of-sight transmission and, when satellite time was available, satellite transmission.



GSM = ground station module JTF = joint test force

Figure 6-1. Test and V&V Configuration

Despite the extensive testing conducted prior to the first flight, it was still impossible to verify and validate the ETE Test synthetic environment. When the aircraft took off, the environment became dynamic. As the aircraft proceeded toward Fort Hood and the entity starting positions were loaded in the database, the relationship of

the aircraft was constantly changing with respect to the satellite.

In addition, once the aircraft arrived on station, it flew an orbit that allowed it to keep the mission area within the radar field of view. As the aircraft banked during the turn at each end of the orbit, the orientation of the aircraft's satellite antenna changed with respect to the satellite. When the aircraft banks toward the satellite, reception should improve, and when it banks away, reception should worsen. Pretest calculations indicated that there was a possibility that data would be lost.

As a result, part of the actual test flights involved the V&V of the satellite link under operational conditions. V&V data were collected simultaneously with test data and the results could not be analyzed until after the test flights were completed. The V&V results showed that data were lost during the flight, however the loss was small enough that it did not affect the validity of the link and the subsequent mission.

7. High Level Architecture (HLA) Challenges and Benefits

Even though JADS will end in March 2000, it appears that VSTARS will remain as a valuable legacy product. It has been adopted by the Joint STARS Joint Program Office and the Air Force as the Joint STARS radar model. It will be used for the joint training of mission crews and common ground station (CGS) crews. It is scheduled for use in the testing of the CGS and is being considered for the testing of the Block 20 E-8.

This means that VSTARS will become HLA compliant in the near future. This will offer challenges and benefits as the transition is made. I will briefly discuss these issues in the context of this paper.

Very little change will be required to describe the ETE Test synthetic environment in terms of a federation and federates. The ETE Test SE was requirements based. Each object in the environment was defined in terms of required actions and functions, input data, and output data.

The need for the VSTARS data packet, coordinate conversion, the broadcast issues, and the need for controlling the flow of data over the satellite link are all reasons for the use of a runtime interface (RTI).

In addition, much of the control of the environment was ad hoc at best. We actually had, at one point, a four, three, two, one, start your simulations take place over the telephone. Using HLA, most of this exercise control can be automated.

What then are the challenges? The challenges are the same as were present in the ETE Test synthetic environment: namely latency and overload of the environment. The RTI, by its very nature, is bound to add some latency to the system. Fortunately, a system of this type is very tolerant to latency.

Overload is a challenge for at least two reasons. All of the potential users of the environment have said that 10,000 entities are great, but 100,000 would be better. Will the RTI handle that kind of load? The other challenge is bandwidth. Even HLA cannot overcome the fact that the pipe is only so big.

8. Conclusion

The ETE Test proved that ADS could be used to test Joint STARS and other systems in their operational environment using DIS. It also showed that major modifications had to be made to the DIS standard to make it work under the conditions of the ETE Test. It would appear to the author that HLA offers a promise of reducing the complexity inherent in operational tests of complex systems of systems such as Joint STARS.

9. References

[1] Standard for Distributed Interactive Simulation – Application Protocols Version 2.0 Fourth Draft (Revised), IST-CR-94-50, March 16, 1994.

Author Biography

GARY J. MARCHAND is the technical lead for the End-To-End Test of the Joint Advanced Distributed Simulation Joint Test Force. He retired from the U.S. Army in 1993 as a colonel after having been the deputy director at TRAC-WSMR. He is currently employed as a senior analyst by Science Applications International Corporation.